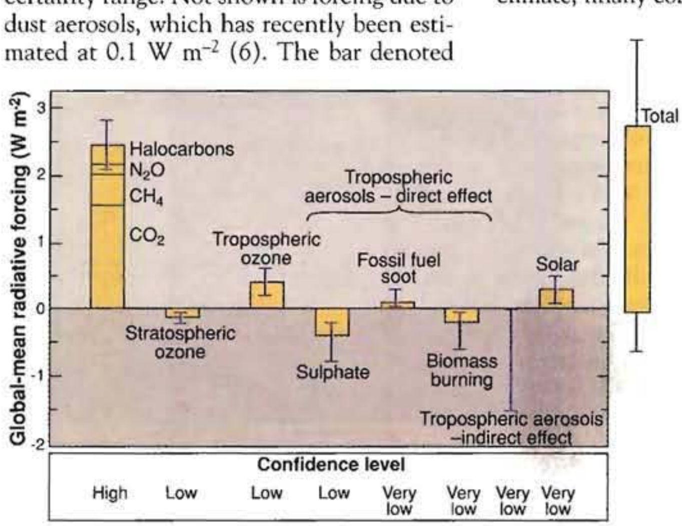
Uncertainty in Climate Change Caused by Aerosols

Stephen E. Schwartz and Meinrat O. Andreae

The National Research Council (NRC) recently issued a report "A Plan for a Research Program on Aerosol Radiative Forcing and Climate Change" (*1*) that underscores the importance of anthropogenic aerosols as agents of climate change. Atmospheric aerosols are suspensions of microscopic and submicroscopic particles; in industrial regions and over much of the Northern Hemisphere, their sources are dominated by human activity. Anthropogenic aerosols influence climate directly, by scattering solar radiation, and indirectly, by modifying cloud properties. Of all atmospheric pollutants, aerosols are the most evident because they restrict visibility and whiten the otherwise deep blue of the sky, yet understanding of their influence on climate change is beset with uncertainty. Although the NRC report stresses the need to reduce these uncertainties, in our view it does not go far enough.

The climatic influence of aerosols is complex. Light scattering by aerosols decreases penetration of solar radiation through the atmosphere and absorption at the surface, thereby exerting a cooling influence. This scattering by aerosols can readily be observed from aircraft as a whitish veil over the landscape. The presence of anthropogenic aerosols is thought to have roughly doubled the amount of light scattered back into space by particles in the atmosphere (*2*). In addition, increased aerosol particle concentrations, by increasing cloud droplet concentrations, enhance cloud reflectivity and inhibit precipitation development, causing clouds to persist longer and resulting in still more reflection of sunlight (*3*). The decrease in absorption of solar radiation due to anthropogenic aerosols, the "forcing" of climate by these aerosols, is estimated to be comparable, but of opposite sign, to climate forcing resulting from increased absorption of terrestrial infrared radiation by enhanced atmospheric concentrations of CO_2 and other polyatomic molecules, the anthropogenic "greenhouse" forcing (*4*).

This situation is illustrated in the figure, which shows current estimates by the Intergovernmental Panel on Climate Change (IPCC) (*5*) of global and annual mean radiative forcing over the industrial period. The cooling influence attributed to stratospheric ozone is attributable mainly to a decrease in the concentration of this greenhouse gas. A slight warming influence is ascribed to soot aerosols, which are efficient light absorbers. The IPCC gave no estimate for the indirect aerosol effect, only an uncertainty range. Not shown is forcing due to dust aerosols, which has recently been estimated at 0.1 W m^{-2} (*6*). The bar denoted "Total," which we have added, is roughly the same as that for the long-lived greenhouse gases alone.



Forcing the issue. Estimates of the globally and annually averaged anthropogenic radiative forcing of climate due to (i) changes in concentrations of greenhouse gases and aerosols from preindustrial times to the present and (ii) natural changes in solar output from 1850 to the present (*5*). The bars denote a mid-range estimate for each forcing (an upward bar denotes a positive forcing or warming influence; a downward bar, a cooling influence); the I-beams show an estimate of the uncertainty range. Bar at right shows the total forcing as the algebraic sum of the individual component forcings and the uncertainty range for the total forcing as the sums of the upper and lower ends of the individual uncertainty ranges. The lower panel indicates the IPCC's subjective confidence that the actual forcing lies within the indicated uncertainty range.

The picture changes markedly, however, when the very large uncertainties in current estimates of aerosol forcing are considered. If the magnitude of aerosol forcing is at the low end of the uncertainty range, aerosols are negating only a small fraction of the greenhouse forcing. However, if the aerosol forcing is at the high end of the uncertainty range, aerosols could be negating virtually all of the present greenhouse forcing.

Let us suppose that aerosols are in fact negating much of the greenhouse forcing, a possibility wholly consistent with present uncertainties. Then the temperature increase over the industrial period, about 0.5 K for the global and annual average (*5*), if due to these forcings at all, must be due to the rather slight residual, indicating a much greater planetary temperature sensitivity than if the aerosol forcing is small. And if temperature sensitivity is high, global warming may accelerate sharply in the future. Climate models do not help much to narrow this uncertainty, as global and annual mean temperature sensitivities of current climate models vary by a factor of 3 (*7*). Paleoclimate studies yield comparable uncertainties (*8*).

The NRC panel report (*1*) provides a clear and concise summary of the current state of knowledge about aerosol forcing of climate, finally concurring in the IPCC estimates of forcing and uncertainty. It then outlines a detailed and well-thought-out plan of process-related research and satellite-based measurements to reduce the uncertainty in aerosol forcing to some ±15% globally and locally, comparable to the uncertainty in greenhouse gas forcing.

Although we concur in this objective, we are concerned that the report does not adequately convey a sense of urgency in reaching it. Without greatly narrowing the uncertainty in aerosol forcing, there will exist little observational basis for the nature and magnitude of climate response to increasing concentrations of greenhouse gases. We wish the authors of the NRC report had emphasized more strongly that because of the vastly different residence times of greenhouse gases (decades to centuries) and tropospheric aerosols (about a week), negation of greenhouse forcing by aerosol forcing means that forcing due to one week's emissions of aerosol precursors is negating forcing due to decades of past CO_2 emissions, whereas each week's co-emitted CO_2 is adding to an ever accumulating burden of this greenhouse gas. Clearly, the longer we postpone getting the knowledge of the aerosol forcing that is required to address the policy implications of this realization, the deeper the hole we are digging for

S. E. Schwartz is in the Environmental Chemistry Division, Brookhaven National Laboratory, Upton, NY 11973, USA. E-mail: ses@bnl.gov
M. O. Andreae is in the Department of Biogeochemistry, Max Planck Institute of Chemistry, D-55020 Mainz, Germany. E-mail: moa@diane.mpch-mainz.mpg.de

ourselves with respect to the greenhouse effect and its potential repercussions on future generations.

In our view, the NRC panel seriously underestimates the research effort required to reduce the uncertainty in aerosol forcing to the specified level. The task of characterizing tropospheric aerosols, their spatial and temporal variability, their size-dependent chemical and physical properties, and their optical and cloud-nucleating effects; of understanding the processes controlling these properties and effects; of representing these processes in models; of evaluating the performance of these models; and of representing these effects in climate models requires a research effort several-fold greater than that outlined in the report. In the absence of this research, knowledge of climate response to greenhouse forcing necessary for confident policymaking will be reliant entirely on climate models having little credible empirical confirmation.

References and Notes

1. National Research Council, Panel on Aerosol Radiative Forcing and Climate Change (J. Seinfeld, Chair), *A Plan for a Research Program on Aerosol Radiative Forcing and Climate Change* (National Academy Press, Washington, DC, 1996).
2. M. O. Andreae, in *Future Climate of the World*, A. Henderson-Sellers, Ed. (Elsevier, Amsterdam, 1995), pp. 341–392.
3. S. E. Schwartz and A. Slingo, in *Clouds, Chemistry and Climate*, P. Crutzen and V. Ramanathan, Eds. (Springer, Heidelberg, 1996), pp. 191–236; B. A. Albrecht, C. S. Bretherton, D. Johnson, W. H. Schubert, A. S. Frisch, *Bull. Am. Meteorol. Soc.* **76**, 889 (1995).
4. R. J. Charlson *et al.*, *Science* **255**, 423 (1992); J. T. Kiehl and B. P. Briegleb, *ibid.* **260**, 311 (1993); J. T. Kiehl and H. Rodhe, in *Aerosol Forcing of Climate*, R. J. Charlson and J. Heintzenberg, Eds. (Wiley, Chichester, 1995), pp. 281–296; A. Jones, D. L. Roberts, A. Slingo, *Nature* **370**, 450 (1994).
5. Intergovernmental Panel on Climate Change, *Climate Change 1995: The Science of Climate Change*, J. T. Houghton *et al.*, Eds. (Cambridge Univ. Press, Cambridge, 1996).
6. I. Tegen, A. A. Lacis, I. Fung, *Nature* **380**, 419 (1996).
7. R. D. Cess *et al.*, *J. Geophys. Res.* **95**, 16601 (1990); J. F. B. Mitchell, C. A. Senior, W. J. Ingram, *Nature* **341**, 132 (1989).
8. J. E. Hansen, A. Lacis, R. Ruedy, M. Sato, H. Wilson, *Natl. Geogr. Res. Explor.* **9**, 142 (1993).

9. S.E.S. acknowledges support from the U.S. Department of Energy.